Assessing conservation effects on water quality in the St. Joseph River Watershed

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Summary

Agriculture is a major contributor to non-point source pollution of streams, rivers and lakes. The St. Joseph River is a major drinking water source in northeastern Indiana that has been contaminated by chemicals in runoff. A Source Water Protection Initiative project began in 2002, with the focus on evaluating agricultural practices to reduce pesticide losses. Subsequently, this effort then became a part of the US Department of Agriculture's nationwide Conservation Effects Assessment Project with the focus expanded to include nutrients and sediment as water quality concerns. The Cedar Creek Watershed encompasses about 707 km^2, and topography is flat to gently rolling, with many depressional areas, and monitoring is currently being conducted on 12 catchments ranging from 2 to 19,000 hectares. A pair of field sites allows comparisons between the effects of conventional and no-till farming practices on runoff, sediment, nutrient, and pesticide losses. Another pair of small field monitors allows examination of the impacts of surface tile inlets and/or blind inlet drains and associated management practices on water quality. Eight sampling sites on three sets of larger nested watersheds monitor runoff, nutrients and pesticide losses in the large drainage ditches and in Cedar Creek itself. A network of automated weather stations and soil moisture sensors has been deployed to provide detailed information on the complete hydrologic cycle in the watershed. Laboratory flume studies as well as field rainfall simulation experiments have also been conducted to expand our knowledge of the pesticide and nutrient transport processes. Watershed water quality model calibration and validation utilizing the SWAT and AnnAGNPS models have been conducted as well. This presentation will present results from the past six years, and discuss what we have learned during that time. Many challenges still exist to allow evaluation of the true impacts of conservation practices on water quality.

Keywords: water quality, land management, soil conservation, monitoring, modeling

Introduction

Agriculture is a major contributor to water quality concerns in streams, rivers and lakes. Sediment from soil erosion, nutrients from fertilizer or manure applications, and pesticides from weed, insect or other pest control can all move off-site from farmers' fields and be transported far away and impact water bodies and water users. The majority of agricultural croplands in the United States are treated with herbicides to control weeds, and in some cases unacceptable amounts of these materials may end up in rivers. Many communities use rivers as the source of their drinking water supply.

In the state of Indiana in the midwestern U.S. (Figure 1), the city of Ft. Wayne has the intake for its drinking water on the St. Joseph River (Figure 2). The River's watershed covers an area of 2809 km^2, and extends across northeastern Indiana, southeastern Michigan, and northwestern Ohio (Figure 2). The water treatment plant pumps 129 million liters of water daily from the river for treatment and use by approximately 250,000 people (SJRWI, 2003a).

Figure 1. Location of the St. Joseph River Watershed in the midwestern United States.

Finished tap water samples from Ft. Wayne were tested every three days for two common herbicides (atrazine and cyanazine) by a network of environmental groups (Environmental Working Group – EWG) in the spring and summer of 1995. All 14 samples tested contained atrazine, with an average concentration of 3.7 ppb, and a peak concentration of 10.0 ppb, while cyanazine was detected 71% of the time with an average concentration of 1.4 ppb and a peak concentration of 4.8 ppb (EWG, 1995). Subsequently, the Ft. Wayne water treatment plant now tests the intake water to rapidly detect herbicides in the intake water during susceptible time periods. More powdered activated carbon can then be added to the treatment process to reduce the levels of herbicides in the water before they reach consumers (City of Ft. Wayne, 2008). The current EPA Maximum Contaminant Level (MCL) for atrazine in drinking water is 3.0 ppb on a rolling average annual basis (USEPA, 2008).

After the study by the EWG, the Ft. Wayne water treatment plant and the St. Joseph River Watershed Initiative (SJRWI) cooperatively monitored the water quality at about 20 sites within the St. Joseph watershed for eight months out of the year with weekly grab samples from 1996-

1998. Their results showed that average atrazine concentrations at all the sites ranged from 1.2 to 2.7 ppb, and peak atrazine concentrations ranged from 6.7 to 17.0 ppb (SJRWI, 2003b).

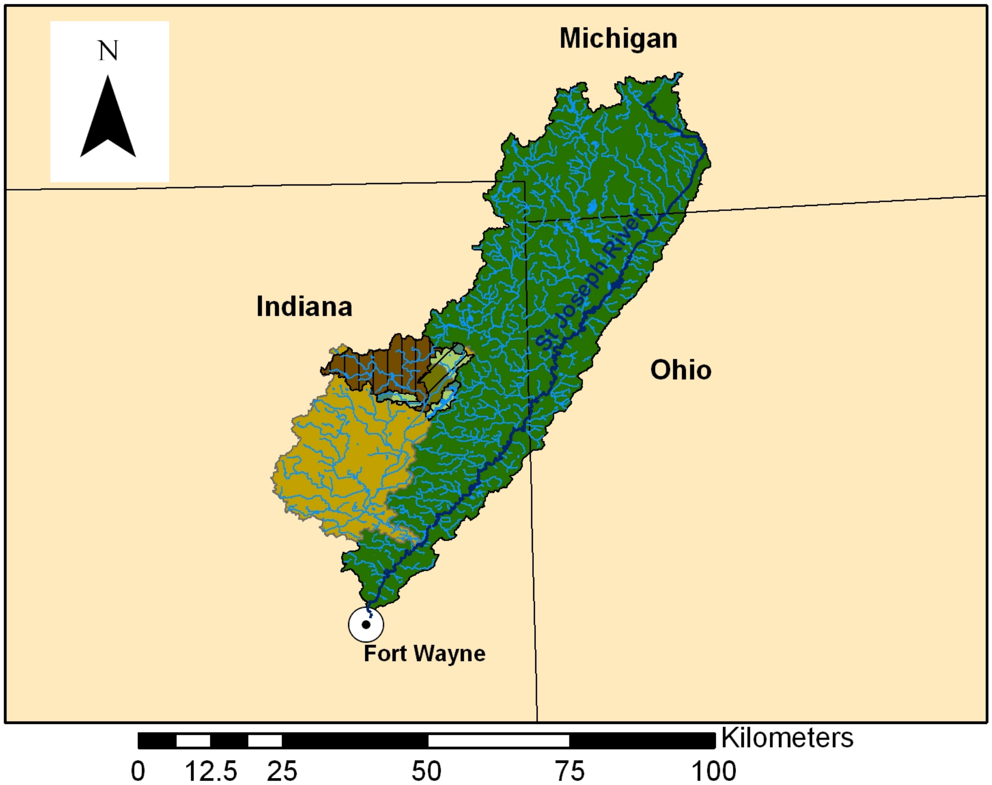

Figure 2. The St. Joseph River and watershed are the source water for the city of Fort Wayne, Indiana. The Cedar Creek subcatchment is shown in shades of tan and brown.

A Source Water Protection Initiative (SWPI) project began in 2002 with special Congressional funding to the USDA-Agricultural Research Service (ARS) National Soil Erosion Research Laboratory (NSERL) to conduct research in the St. Joseph River Watershed to determine the transport and fate of agricultural chemicals, and the effectiveness of existing and new best management practices (BMPs) to reduce losses of herbicides to the river. This effort subsequently became part of the nationwide ARS Conservation Effects Assessment Project (CEAP), which has the goal of determining the impact of soil conservation practices on off-site water quality (among others).

This paper will describe some of the monitoring and modeling research that has been conducted by the NSERL in the St. Joseph River watershed over the past six years, present some summary results, and discuss implications of these results and new directions of this research program.

Materials and methods

The St. Joseph River watershed is mostly agricultural (79%), with major crops of corn and soybeans, and minor crops of winter wheat, oats, alfalfa, and pasture. Livestock (swine, cattle, poultry, dairy) are also present, with a few very large operations. Ten percent of the watershed is woodlands and wetlands, while urban areas, farmsteads and other land uses comprise the remaining 11% (SJRWI, 2003a). Cedar Creek (Figure 2) is the largest tributary to the St. Joseph River, and drains about 707 km^2.

Research efforts by the NSERL from 2002-2008 have been focused in the upper Cedar Creek catchment (Figures 2 and 3), with a combination of base flow and storm event water sampling from drainage ditches and small field sites.

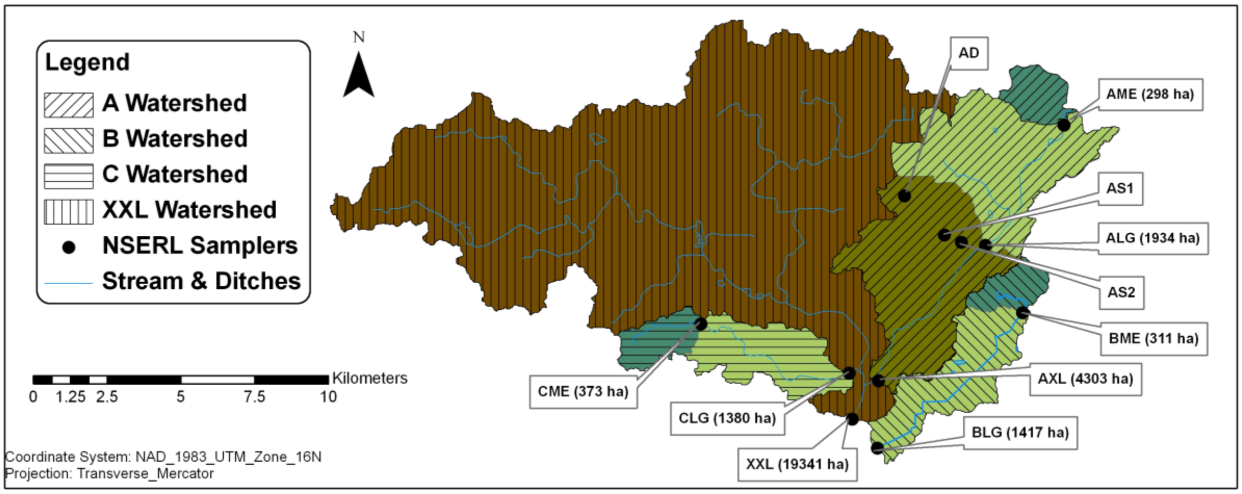

Figure 3. Portion of Upper Cedar Creek, with NSERL watersheds and water quality monitoring sites shown.

The experimental design basically consists of 3 sets of nested watersheds for ditch water quality monitoring (watershed A, B, and C in Figure 3 and Table 1), as well as three small field watershed sites (AS1, AS2, and AD). Other related laboratory and field rainfall simulation experiments have also been conducted.

Figure 4. Modified drop-box weir (left) and automatic samplers and weather station (right) at small field AS1 monitoring site.

Table 1. Instrumented watersheds and characteristics.

ID	Description	Area (ha)[1]	Major Soils[2]	Land Use/Cropping[1]
XXL	Upper Cedar Creek stream site, south of town of Waterloo, IN	19341	Blount silt loam, Pewamo silty clay, Glynwood loam, Rawson sandy loam, Rensselaer loam, Sebewa sandy loam	74% Agriculture 14% Grass/Pasture 8% Forest 3% Developed
AXL	Very large watershed near Cedar Creek, and has historic data from SJRWI studies. Planned to be BMP w.s.	4303	Blount silt loam, Pewamo silty clay, Glynwood loam, Rawson sandy loam, Rensselaer loam, Sebewa sandy loam	78% Agriculture 14% Grass/Pasture 6% Forest
ALG	Large watershed nested within AXL.	1934	Blount silt loam, Pewamo silty clay, Glynwood loam, Rawson sandy loam, Morley silty clay loam	77% Agriculture 16% Grass/Pasture 6% Forest
AME	Medium watershed nested within ALG and AXL.	298	Rawson sandy loam, Pewamo silty clay, Morley silty clay loam, Blount silt loam	79% Agriculture 15% Grass/Pasture 4% Forest
AS1	Small field watershed within AXL under cont. no-till; has full on-line weather station.	2.2	Pewamo silty clay, Glynwood loam, Morley silty clay loam	100% Agriculture
AS2	Small field watershed, east and south of AS1 – under continuous conventional tillage.	2.7	Glynwood loam, Blount silt loam	100% Agriculture
AD	Field site, consisting of two closed depression sub-basins, both w/ tile inlet & french drain	East 5.7 West 4.6	Pewamo silty clay, Glynwood loam, Morley silty clay loam, Wallkill silt loam	100% Agriculture
BLG	Large watershed, ditch was dredged in 2003-2004. To be used as first control.	1417	Blount silt loam, Pewamo silty clay, Glynwood loam, Sebewa sandy loam, Rensselaer loam	83% Agriculture 12% Grass/Pasture 3% Forest
BME	Medium watershed nested within BLG – ditch was dredged in 2003-2004.	311	Blount silt loam, Pewamo silty clay, Glynwood loam	85% Agriculture 8% Grass/Pasture 6% Forest
CLG	Large watershed to be used as second control	1380	Blount silt loam, Pewamo silty clay, Glynwood loam, Morley silty clay loam	73% Agriculture 17% Grass/Pasture 5% Forest
CME	Medium watershed nested within CLG	373	Glynwood loam, Blount silt loam, Pewamo silty clay	83% Agriculture 10% Grass/Pasture 4% Forest

[1] All areas except four small watersheds (AS1, AS2, AD1, AD2) obtained from HYMAPS Watershed Delineation Map Interface.
[2] Soil information obtained from DeKalb County Soil Survey (USDA-SCS, 1982).

Automated ISCO 6712 samplers are used at the ditch monitoring sites, and ISCO Avalanche and 6712 samplers are used at the field monitoring sites (ISCO, Inc., Lincoln, NE). Stage of water in the ditches is measured with ISCO 720 level transducers and flow velocity is measured with ISCO 2150 AVF sensors (ISCO, Inc., Lincoln, NE) every 10 minutes. The ditch sites are monitored for base flow with 50 ml draws every 4 hours, with 6 draws composited into a single bottle for daily water quality analyses. Additionally, should a runoff event occur the rising stage of the ditch water will trigger event sampling in which 100 ml of the water is collected every 30 minutes (3 draws composited into a single bottle every 1.5 hours). At the small field sites (AS1 and AS2), surface runoff through the drop-box weir will trigger the samplers, and a pair of samplers will collect bottles for nutrient/herbicide and sediment concentration determination. At the beginning of an event, 300 ml of water are collected every 30 minutes for chemical analyses while 900 ml of the runoff are collected every 30 minutes for sediment determination. The ISCO 6712 ditch samplers are cooled with a custom built thermostatically controlled chilling system that maintains the sample bottles in a $4^{o}C$ water bath. The ISCO Avalanche samplers are refrigerated, and the sediment samples at the small field sites require no cooling. At the depression (AD) site, 100 ml water quality samples are taken at the beginning of a drainage event and every 30 minutes after that (3 draws composited into a single bottle). Sediment samples are at the same times as the water quality ones, except 300 ml samples are pulled (instead of 100 ml).

All runoff water samples for herbicide analysis are filtered (0.45 µm) into glass vials, and frozen immediately until analysis can be performed. Atrazine, simazine, acetochlor, alachlor, and metolachlor are preconcentrated by solid-phase microextraction according to a modified EPA method 525.2 described by Rocha et al. (2007), and quantified by gas chromatography with mass spectrometry. The detection limit for atrazine, acetochlor, alachlor, and metolachlor is 0.25 ppb, while the detection limit for simazine is 0.5 ppb. Glyphosate is quantified by high performance liquid chromatography with post-column derivitization and fluorescence detection, according to EPA method 547 (U.S. EPA, 1990) (detection limit = 2 ppb).

For nutrient analyses, a runoff water subsample of 60 ml is initially removed for later digestion, while a 20 ml aliquot is filtered (0.45 µm) and acidified with concentrated sulfuric acid to $pH<2$. Processed subsamples are frozen until laboratory analyses can be performed. Colorimetric analyses are conducted on a KoneLab Aqua 20 (EST Analytical, Medina, OH). Soluble P (SP) is analyzed with EPA method 365.2 (U.S. EPA, 1983), nitrate (NO_3-N) is determined using EPA method 353.1 (U.S. EPA, 1983), and ammonium (NH_4-N) is analyzed using EPA method 365.2 (U.S. EPA, 1983). Unfiltered water samples are digested with mercuric sulfate, and then analyzed with EPA method 351.2 for Total Kjehldahl N (TKN) and EPA method 365.4 for Total Kjehldahl P (TP) (U.S. EPA, 1983).

Each year on average, over 3500 water samples and 300,000 environmental observations are obtained from the 12 automated water quality monitoring sites. This requires extensive database management to efficiently store and retrieve the data. Water sample nutrient, herbicide, sediment, and pH results are stored in an analyte database. Flow data is also imported into the analyte database. Algorithms within the database merge the water flow data with the analyte concentration data to calculate analyte loss from each subbasin. There are five weather, stream flow, and soil moisture monitoring stations and seven stations monitoring stream flow and precipitation located within the watershed. Measurements at the weather and soil monitoring stations consists of rainfall, total solar radiation, relative humidity, air temperature, wind speed/direction, and soil moisture and temperature at 5, 20, 40, and 60 cm depths. Data are recorded every 10 minutes and transmitted hourly to a database which can be retrieved via a web-based interface (http://milford.nserl.purdue.edu/swpi/). Cropping, tillage and management information, collected from producer surveys, are stored in a geodatabase. The databases are designed to support the laboratory's modeling efforts, as well as a variety of experimental research studies. This local database is designed to be incorporated into the national CEAP STEWARDS database.

Results and discussion

Precipitation and flow measured at the watershed sites during the monitoring periods are shown in Table 2. While long-term average annual precipitation for the area is nearly 900 mm, the results in the table are less than this because they only include precipitation during the time when the stream and field water quality monitoring sites are active, which is typically April through October of each year. Samplers are removed during the winter, to prevent damage from freezing temperatures.

Table 2. Precipitation and discharge recorded during the monitoring periods[a] for watersheds from 2002 to 2007.

Site	2002	2003	2004	2005	2006	2007
	mm					
Precipitation[a]	321	727	627	416	606	564
AS1	na	na	32.3	8.0	12.3	na
AS2	na	na	59.1	10.9	34.9	na
ADE	na	na	na	na	12.5	9.8
ADW	na	na	na	na	42.0	22.3
AME	na	65.3	103	42.8	154	209
ALG	25.7	70.9	146	85.6	342	235
AXL	33.3	243	357	274	254	233
BME	8.11	235	115	62.8	240	202
BLG	10.6	169	83.9	19.7	470	183
CME	na	117	178	6.0	226	306
CLG	na	213	299	145	181	212
XXL	na	na	na	na	177	152

[a]Monitoring periods were typically from ~4/1 to ~10/31 each year.

Table 3. Flow-weighted Average herbicide concentrations determined by daily + storm sampling for 2004-2007.

Flow –Weighted Average Concentrations (ppb)						
Site	Atrazine	Simazine	Acetochlor	Alachlor	Metolachlor	Glyphosate
XXL	3.5	0.4	0.9	0.0	1.0	0.1
AXL	3.4	0.5	0.4	0.1	1.3	0.3
ALG	2.8	0.4	0.5	0.1	0.9	0.1
BLG	7.3	1.5	0.4	0.1	3.9	0.7
CLG	3.0	0.3	0.7	0.1	2.6	0.1
AME	0.9	0.0	0.2	0.1	0.4	0.1
BME	9.8	1.4	0.2	0.1	6.4	0.3
CME	6.3	2.0	3.9	0.1	0.6	0.3

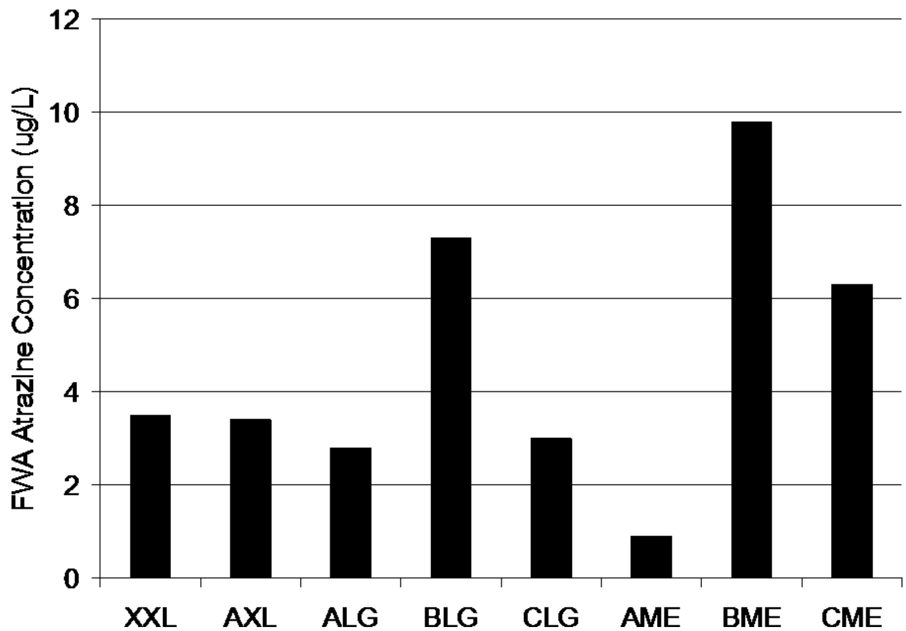

Figure 5. Flow-weighted average atrazine concentrations from watersheds for 2004-2007.

Table 4. Maximum observed herbicide concentrations determined by daily + storm sampling for 2004-2007.

Maximum Observed Concentrations (ppb)						
Site	Atrazine	Simazine	Acetochlor	Alachlor	Metolachlor	Glyphosate
XXL	37.7	7.9	9.6	2.6	22.5	24.5
AXL	69.2	22.7	48.6	10.6	23.1	68.7
ALG	79.2	12.9	52.5	5.4	16.8	48.8
BLG	417.0	23.7	33.3	1.9	180.6	117.3
CLG	91.2	13.8	33.1	4.0	344.2	61.0
AME	42.1	7.7	21.1	2.6	32.8	22.6
BME	155.1	38.2	5.2	4.3	69.7	240.4
CME	152.0	44.9	74.6	4.3	11.2	12.1

For the crop growing seasons 2004-2007, flow-weighted average (FWA) concentrations of simazine, alachlor, metolachlor, and glyphosate did not exceed their respective MCL values, and FWA acetochlor concentrations were below 1 ppb (Table 3). In some cases maximum observed concentrations of atrazine exceeded 400 ppb, while all values for glyphosate were below its MCL of 700 ppb (Table 4). Average atrazine levels ranged between sites from 0.9 – 9.8 ppb for the four seasons, and were at or above the MCL of 3.0 ppb at sites XXL, AXL, BLG, CLG, BME, and CME. These results indicate that atrazine losses from the studied watersheds impact intake water quality in Cedar Creek and ultimately the St. Joseph River, especially during May and June of each year, and can contribute to causing additional filtration steps to be necessary at the Ft. Wayne water treatment plant.

In a rainfall simulation study conducted at the AS1 and AS2 field sites, maximum glyphosate concentration in runoff was 233 ppb for no-til (NT) and 180 ppb for conventional tillage (CT) (approximately 33% and 26% of the maximum contaminant limit (MCL) for glyphosate (700 ppb), respectively, while maximum atrazine concentration in runoff was 303 ppb for NT and 79 ppb for CT (approximately 100 times and 26 times the atrazine MCL (3 ppb)). Atrazine concentration and loading were significantly higher in runoff from NT plots than from CT plots, whereas glyphosate concentration and loading were impacted by tillage treatment to a much lesser degree (Warnemuende et al, 2007). These results suggest that glyphosate-based weed management may represent a lower drinking water risk than atrazine-based weed management, especially in NT systems. Although no-till has many soil conservation benefits, it should not be considered a pesticide BMP, at least on these soils and in these watersheds.

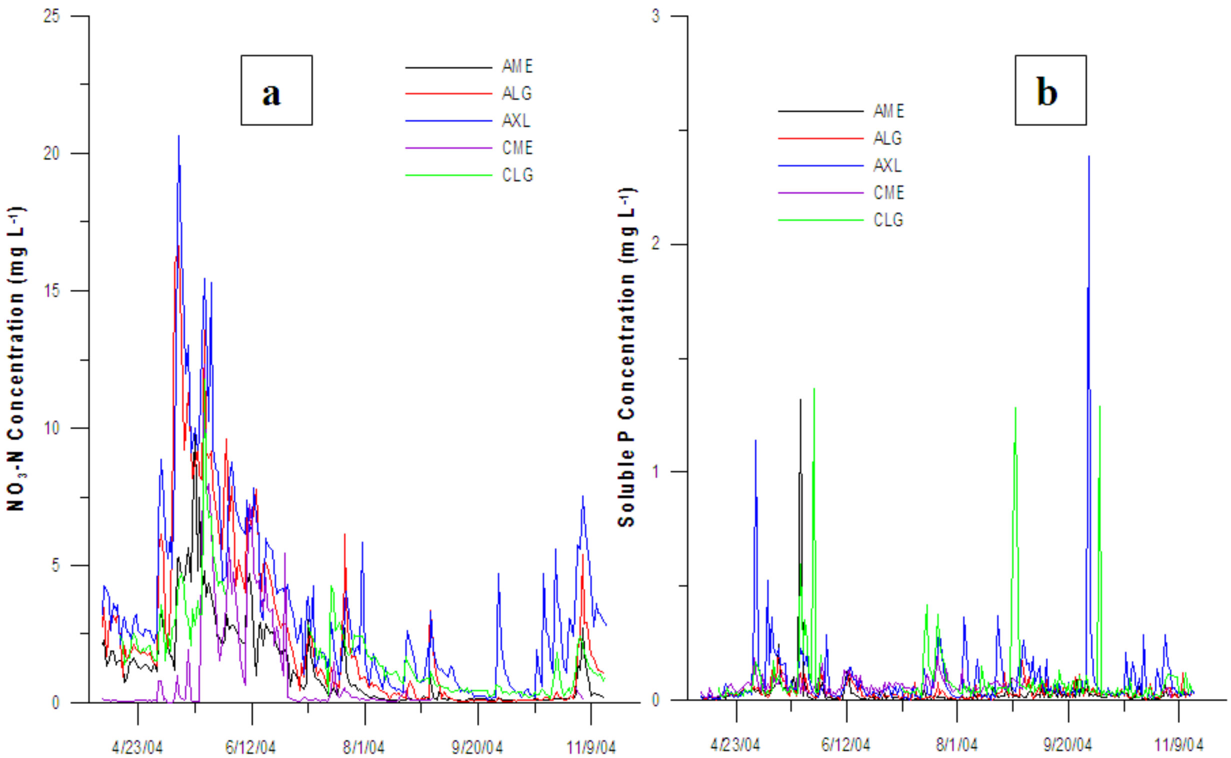

Figure 6. (a) Nitrate-N and (b) soluble-P concentrations observed in water samples collected at selected watershed sites during 2004 monitoring period.

Nutrient losses of most concern from agriculture are typically soluble nitrate-N and soluble P. Concentrations of nitrate-N in water samples from our monitoring sites can often exceed the EPA drinking water standard of 10 ppm (Figure 6a). In 2004, peak concentrations at some of the ditch sites reached 20 ppm. A common scenario for large losses of nitrogen in the water is planting and fertilizer application on corn crops, followed shortly thereafter by heavy rainfall and runoff events. The graph in Figure 6a would be typical for a wet year – other years in our monitored data where the spring weather has been dryer (e.g. 2005) do not show such high peak concentrations. Soluble phosphorus concentrations do not often exceed 1.5 ppm, and do not show the same seasonal high tendencies in spring as nitrate, and instead are associated with both small and large storm events throughout the year (Figure 6b). Peaks in soluble P concentations that we have observed in the late summer and fall are likely due to leaching of phosphorus from crop leaves that have fallen to the ground surface during senescence.

We evaluated the performance of two water quality models in accordance with specific tasks designated in the CEAP project. The Soil and Water Assessment Tool (SWAT, Arnold et al., 1998) and the Annualized Agricultural Non-Point Source Pollution (AnnAGNPS, Bingner and Theurer, 1995) models were applied uncalibrated to the Cedar Creek Watershed (CCW) within the St. Joseph River Watershed in northeastern Indiana to predict streamflow, sediment transport and atrazine losses. In order to ultimately assess the benefits of conservation practices in agricultural watersheds, which is one of the major goals of CEAP, proper application of models is essential, as well as baseline comparisons made in the uncalibrated mode aimed at eliminating any bias due to parameter optimization. This study found that for streamflow predictions the performance of SWAT was numerically superior to AnnAGNPS, with Nash-Sutcliffe (1970) model efficiency (ME) values for SWAT ranging from 0.77 to 0.25, and for AnnAGNPS ranging from 0.13 to –2.06, for monthly and annual streamflow, respectively. Neither model was able to adequately simulate atrazine loss concentrations in an uncalibrated mode. Overall results suggest that for model applications in CEAP at the watershed scale for this study, the use of the SWAT model would be preferable to AnnAGNPS in terms of overall model performance and usability of modeling technology (see Heathman et al., 2008 for more details).

In another modeling study (Larose et al., 2007), the SWAT model was used to estimate streamflow and atrazine losses to surface water in the Cedar Creek Watershed. Model calibration and validation periods consisted of five and two year periods, respectively. The National Agricultural Statistics Survey (USDA-NASS, 2001) land cover classification and the Soil Survey Geographic (SSURGO) database (USDA-NRCS, 2004) were used as model input data layers. SJRWI data and information from the Soil and Water Conservation Districts of Allen, Dekalb, and Noble counties were used to represent agricultural practices in the watershed which included the type of crops grown, tillage practices, fertilizer and pesticide application rates. Model results were evaluated based on efficiency coefficient values, standard statistical measures, and visual inspection of the measured and simulated hydrographs. Model efficiency for monthly and daily streamflow calibration and validation ranged from 0.51 to 0.66. For atrazine calibration and validation, ME ranged from 0.43 to 0.59. All ME values were within the range of acceptable model performance standards. This work showed that SWAT is an effective model for simulating the dynamics of streamflow and atrazine concentrations on a large-scale agricultural watershed in the midwestern USA. Please see Larose et al., 2007 for more details.

Summary and Conclusions

The results of our efforts to this point in the St. Joseph River Watershed indicate that there are a large number of factors influencing pollutant transport and fate. Losses of some chemicals, such as atrazine and nitrate-N are largely influenced by the date of application and occurrence of subsequent large rain storm events that can rapidly transport these soluble materials. Also, some soil conservation practices such as no-till, may not be beneficial for reducing losses of soluble chemicals such as atrazine. Observations of the topography and flow patterns in the watersheds have also highlighted the fact that only a small fraction of the runoff from the land moves directly from the soil surface into a drainage ditch. There is a predominance of tile drainage as well as surface tile riser inlets, which allow direct conductance of surface runoff water to ditches and streams, carrying with it sediment, pesticides and nutrients. Management practices to reduce losses of agricultural chemicals to off-site water bodies must consider these surface tile inlets, and what practices may be used to manage them. Possible treatments that this project may examine in the future associated with surface inlets will be observing recommended setbacks (currently 20 m for atrazine) where pesticides should not be sprayed around a tile riser, use of vegetative buffer zones around the inlets, and/or use of blind inlets (aka French drains) with soil amendment materials over the buried tile to immobilize the atrazine or other chemicals. Much more intense study of the surface inlets and drainage tile systems is being initiated in 2008, so that numbers and locations of inlet drains and tile outflows to the ditches are documented, and new management practices studied. The AD site (Figure 7) will be the focus of much of this work, as well as additional new field locations.

Figure 7. Surface tile riser inlet at the AD East depression site. A blind tile inlet is also present beneath the surface of the soil here, and the tubing is plumbed so that either can be used to remove water from the depression.

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